Workshop on Particle Production and Thermal Effects in Inflation

Report of Contributions

Contribution ID: **1**　　　　　　　　　　　　　　　　　　Type: **not specified**

A dynamical inflaton coupled to strongly interacting matter

Monday 5 February 2024 10:05 (45 minutes)

In talk I will show how to self-consistently couple the Einstein-inflaton equations to a strongly coupled quantum field theory (QFT) as described by holography. We show that this can lead to an inflating universe, a reheating phase and finally a universe dominated by the QFT in thermal equilibrium. Special attention will be given to technical details that could be of relevance for modelling of more general strongly coupled systems more akin to our own universe.

Presenter: Dr VAN DER SCHEE, Wilke (CERN)

Session Classification: Theory of Particle Production

Contribution ID: **2**   Type: **not specified**

Axion Inflation in the Strong-Backreaction Regime: Decay of the Anber–Sorbo Solution

Monday 5 February 2024 10:55 (45 minutes)

Axion inflation coupled to Abelian gauge fields via a Chern-Simons-like term presents an attractive inflationary model with rich phenomenology, including the production of magnetic fields, black holes, gravitational waves, and possible links to the matter-antimatter asymmetry. In my talk, I will discuss a particular regime of axion inflation, the so-called Anber-Sorbo solution. In this scenario, the gauge-field production provides the dominant source of friction for the motion of the inflaton. I will present the most recent results of me and my collaborators, where we demonstrate that the Anber-Sorbo Solution is unstable. To this end, I will first discuss the "gradient expansion formalism"(GEF), a technique to solve the classical equations of motion for axion inflation in real space. I will then demonstrate how one can use the GEF to study the instability of the Anber-Sorbo solution.

Presenter: VON ECKARDSTEIN, Richard (Institute for Theoretical Physics, University of Münster)

Session Classification: Theory of Particle Production

Contribution ID: **3** | Type: **not specified**

Vector dark matter production during inflation and reheating

Monday 5 February 2024 11:45 (45 minutes)

Gravitational particle production of spectator fields due to the expansion universe during the inflationary and reheating phases of the early universe is of particular interest in the context of dark matter, since it allows to constrain the properties of the dark candidate by comparing the density of particles produced with the observed dark matter abundance. In such processes, tachyonic instabilities arise as a consequence of the coupling to the curvature, greatly enhancing mode production. In this talk, we consider a massive vector field that is coupled to the curvature scalar and the Ricci tensor only, and study its gravitational production through inflation and reheating. We show how the mechanism is more efficient than in the case of a non-minimally coupled scalar field, giving rise to larger abundances. Moreover, we analyze the importance of the coupling to the Ricci tensor, which increases tachyonic instabilities in the system, and constrain the mass of the dark particle and the values of the coupling constants by comparing the corresponding abundance with observations.

Presenter: CEMBRANOS, Jose A. R. (Universidad Complutense de Madrid)

Session Classification: Theory of Particle Production

Contribution ID: **4**   Type: **not specified**

Perturbatively including inhomogeneities in axion inflation

Monday 5 February 2024 14:00 (45 minutes)

Axion inflation, i.e. an axion-like inflaton coupled to an Abelian gauge field through a Chern-Simons interaction, comes with a rich and testable phenomenology. This is particularly true in the strong backreaction regime, where the gauge field production heavily impacts the axion dynamics. Lattice simulations have recently demonstrated the importance of accounting for inhomogeneities of the axion field in this regime. We propose a perturbative scheme to account for these inhomogeneities while maintaining high computational efficiency. Our goal is to accurately capture deviations from the homogeneous axion field approximation within the perturbative regime as well as self-consistently determine the onset of the non-perturbative regime.

Presenter: EMA, Yohei

Session Classification: Theory of Particle Production

Contribution ID: **5**   Type: **not specified**

Making massive spin-2 particles from gravity during and after inflation

Monday 5 February 2024 14:50 (45 minutes)

The phenomenon of cosmological gravitational particle production (CGPP) occurs during and after inflation as quantum fields "feel" the cosmological expansion are excited out of their ground state. CGPP is a compelling and minimal explanation for the origin of dark matter, which might only interact gravitationally, as well as other cosmological relics. In this talk, I'll provide a general introduction to CGPP and then focus on our recent study of CGPP for massive spin-2 particles. I'll briefly discuss the embedding of massive spin-2 particles into the framework of bigravity, present our results for the spectrum of gravitationally produced particles, and discuss a related by-product of our analysis: an FRW-generalization of the Higuchi bound (ghost-avoidance of massive gravity on dS backgrounds).

Presenter: LONG, Andrew (Rice University)

Session Classification: Theory of Particle Production

Contribution ID: **6**   Type: **not specified**

Oscillon formation during inflationary preheating with general relativity

Tuesday 6 February 2024 10:00 (45 minutes)

In this talk, I describe the use of numerical relativity simulations to study the non-perturbative evolution of inflationary fluctuations during preheating. We find that gravity can enhance the growth of density perturbations, which then collapse and virialize, forming long-lived stable oscillon-like stars. We quantify the compactness of these objects and find that whilst gravitational effects can play an important role in their formation, they are unlikely to collapse into primordial black holes without an additional enhancement of the initial inflationary fluctuations. This talk is based on 2304.01673.

Presenter: AURREKOETXEA, Josu (University of Oxford)

Session Classification: Simulations

Contribution ID: **7**   Type: **not specified**

Lattice simulations during inflation

Tuesday 6 February 2024 10:50 (45 minutes)

Inflationary models with significant amplification of small-scale scalar and tensor perturbations have attracted considerable attention in the literature due to their interesting observational signatures, such as primordial black holes and gravitational waves. However, the large enhancement of fluctuations often challenges our perturbative understanding of inflation. I will present a numerical study of inflation based on lattice simulations. I will show that including nonlinearities has important consequences for the inflationary dynamics and its predictions. I will mainly focus on a specific model known as axion inflation, where the inflaton is coupled to gauge fields via the Chern-Simons interaction. As a second example, I will consider a single-field model of inflation with a resonant feature in the potential.

Presenter: CARAVANO, Angelo (IAP, Paris)

Session Classification: Simulations

Contribution ID: **8**   Type: **not specified**

The strong backreaction in axion inflation: a lattice study

Tuesday 6 February 2024 11:40 (45 minutes)

In this talk, I will address the issue of the strong backreaction regime in the abelian axion inflation scenario. I will review our latest work on lattice simulations of the model, where we present a complete framework to simulate this model. Our work demonstrates that inhomogeneities generated during the evolution at the latest stages of inflation are specially relevant to provide a correct description of the dynamics, and can also lead to a number of new relevant results. Therefore, I will provide a detailed description of the strong backreaction regime and I will compare our results with previous spatially homogeneous semi-analytical studies.

Presenter: LIZARRAGA, Joanes (University of the Basque Country)

Session Classification: Simulations

Contribution ID: **9**   Type: **not specified**

New inflationary probes of axion dark matter

Tuesday 6 February 2024 14:00 (45 minutes)

The QCD axion, serving as a classical dark matter candidate, has a close intriguing interplay with cosmic inflation, a leading paradigm to understand the origin of our universe. In this talk, I will discuss two novel effects of interaction between the inflaton and the Peccei-Quinn (PQ) scalar field (the phase becomes the axion after symmetry breaking). First, the inclusion of the leading high-dimensional operator between the two fields could modify the conventional boundary between inflationary and post-inflationary axions drastically. In particular, a new window could be opened up for the post-inflationary axion, which does not suffer from the axion isocurvature problem. Second, in the feasible inflationary axion scenario, these operators could lead to a whole new suite of cosmological observables for axion isocurvature. They include correlated clock signals in the curvature and isocurvature spectra, and mixed cosmological-collider non-Gaussianities involving both curvature and isocurvature fluctuations with shapes and running unconstrained by the current data.

Presenter: FAN, Jiji

Session Classification: Simulations

Contribution ID: **10**   Type: **not specified**

Lattice Simulations of Gravitational Reheating

Tuesday 6 February 2024 14:50 (45 minutes)

I will present two models for viable gravitational reheating involving a scalar field directly coupled to the Ricci curvature scalar. Crucially to these models are periods of the early Universe where the equation-of-state is stiffer than radiation ($w < 1/3$) resulting in tachyonic growth of the scalar fields energy density. In this talk I will detail the phenomenology and delve into scenarios where lattice simulations are required to make concrete predictions, highlighting interesting avenues for future work.

Presenter: OPFERKUCH, Toby

Session Classification: Simulations

Contribution ID: **11**
Type: **not specified**

Thermalized Axion Inflation

Wednesday 7 February 2024 10:00 (45 minutes)

I analyze the evolution of axion inflation, with gauge fields exponentially amplified by the inflaton velocity. I first review the resulting dynamics, that may lead to friction and oscillations in the inflaton trajectory. I discuss then the effects of interactions of the gauge fields: self-interactions, mediated by the axial coupling, or with Standard model fields. We show that scattering rates involving gauge fields can become larger than the expansion rate, due to the very large occupation numbers, and possibly create and sustain a thermal bath of particles of temperature T during inflation. In the thermal regime, energy is transferred to smaller scales, radically modifying the predictions of this scenario.

Presenter: NOTARI, Alessio (Universitat de Barcelona)

Session Classification: Thermal Effects and Warm Inflation

Contribution ID: **12** Type: **not specified**

Towards understanding non-Abelian axion inflation

Wednesday 7 February 2024 10:50 (45 minutes)

An axion-like inflaton coupling to a non-Abelian gauge sector leads to a scenario which may involve fast thermalization, a computable friction coefficient, control over backreaction effects, and gravitational wave production in various frequency domains. The physics depends on the confinement scale of the non-Abelian sector, and can be either weakly or strongly coupled. We review the main ingredients of this scenario, and outline open problems.

Presenter: LAINE, Mikko Sakari (Universitaet Bern (CH))

Session Classification: Thermal Effects and Warm Inflation

Contribution ID: **13**   Type: **not specified**

Saving Warm Axion Inflation from Light Fermions

Wednesday 7 February 2024 11:40 (45 minutes)

Axion-like particles with a coupling to non-Abelian gauge fields at finite temperature can experience dissipation due to sphaleron heating. This could play an important role for warm inflation or dynamical dark energy. We investigate to what degree the efficiency of this non-perturbative effect depends on the details of the underlying particle physics model. For a wide range of scenarios and energy scales, we find that a previously discussed suppression of sphaleron heating by light fermions can be alleviated. As an outlook, we point out that fermionic effects may provide a new mechanism for ending warm axion inflation.

Based on:

M. Drewes and S. Zell, On Sphaleron Heating in the Presence of Fermions, arXiv:2312.13739

Presenter: Dr ZELL, Sebastian (UC Louvain)

Session Classification: Thermal Effects and Warm Inflation

Contribution ID: **14**   Type: **not specified**

Dark Matter production during Warm Inflation via Freeze-In

Wednesday 7 February 2024 14:05 (45 minutes)

We present a novel perspective on the role of inflation in the production of Dark Matter (DM). Specifically, we explore the DM production during Warm Inflation via ultraviolet Freeze-In (WIFI). We demonstrate that in a Warm Inflation (WI) setting the persistent thermal bath, sustained by the dissipative interactions with the inflaton field, can source a sizable DM abundance via the non-renormalizable interactions that connect the DM with the bath. Compared to the (conventional) radiation-dominated (RD) UV freeze-in scenario for the same reheat temperature (after inflation), the resulting DM yield in WIFI is always enhanced, showing a strongly positive dependence on the

mass dimension of the non-renormalizable operator. Of particular interest, for a sufficiently large mass dimension of the operator, the entirety of the DM abundance of the Universe can be created during the inflationary phase. For the specific models we study, we find an enhancement in DM yield of up to 30 orders of magnitude relative to RD UV freeze-in for the same reheat temperature. Our findings also suggest a broader applicability for producing other cosmological relics, which may have a substantial impact on the evolution of the early Universe.

Presenter: MONTEFALCONE, Gabriele

Session Classification: Thermal Effects and Warm Inflation

Contribution ID: **15**
Type: **not specified**

Warm inflation with sphaleron heating

Wednesday 7 February 2024 14:50 (45 minutes)

Coupling an axion to pure Yang-Mills gauge bosons is a compelling setup for warm inflationary dynamics. The axion, a pseudo-Goldstone boson acting as the warm inflaton is protected from thermal corrections to its mass due by its approximate shift symmetry. Simultaneously, real time sphaleron processes due to the non-trivial topology of the gauge theory fuel particle production, leading to the phenomenon of sphaleron heating. The resulting thermal friction coefficient can be deduced from the sphaleron rate. I will discuss the mechanism of sphaleron heating in the context of warm inflation. In particular, I will examine how the presence of fermions charged under the SU(N) impact the sphaleron dynamics, and outline a path towards a viable warm inflation scenario with QCD sphaleron heating.

Presenter: BERGHAUS, Kim (California Institute of Technology)

Session Classification: Thermal Effects and Warm Inflation

Contribution ID: **16** Type: **not specified**

Future of Cosmological Simulations

Tuesday 6 February 2024 15:40 (1 hour)

This session will be a guided discussion led by Daniel Figueroa. He will start with a visionary talk and introduction to Cosmo-Lattice. Following this, he will engage the audience by posing stimulating questions to stimulate further discussion.

Presenter: FIGUEROA, Daniel G. (Valencia U., IFIC)

Session Classification: Simulations

Contribution ID: **18**
Type: **not specified**

Future of Particle Production in Inflation

Monday 5 February 2024 15:40 (1 hour)

This session will be a guided discussion led by Lorenzo Sorbo. He will start with a visionary talk. Following this, he will engage the audience by posing stimulating questions to stimulate further

Presenter: SORBO, Lorenzo (Massachusetts U., Amherst.)

Session Classification: Theory of Particle Production

Contribution ID: **19** Type: **not specified**

Future of Warm Inflation

Wednesday 7 February 2024 15:40 (20 minutes)

This session will be a guided discussion led by Arjun Berera. He will start with a visionary talk and historical remarks on warm inflation. Following this, he will engage the audience by posing stimulating questions to stimulate further discussion.

Presenter: BERERA, Arjun (Edinburgh U.)

Session Classification: Thermal Effects and Warm Inflation